A CLIMATE-ORIENTED APPROACH
TO TEACHING SCIENCE STANDARDS

CLIMATE LITERACY

ESSENTIAL PRINCIPLES AND FUNDAMENTAL CONCEPTS

FORMAL & INFORMAL EDUCATION

EACH ESSENTIAL PRINCIPLE IS SUPPORTED BY FUNDAMENTAL CONCEPTS COMPARABLE TO THOSE UNDERLYING THE NATIONAL SCIENCE EDUCATION STANDARDS (NSES) AND AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE (AAAS) BENCHMARKS. CONSULT THE **OVERVIEW MATRIX** (UNDER DEVELOPMENT) TO INTEGRATE CLIMATE LITERACY INTO YOUR CURRICULUM.

Climate Literacy: Essential Principles and Fundamental Concepts

This guide was developed with input from recent workshops and discussions and reflects the current efforts in defining climate literacy. It is inspired in part by the work conducted by AAAS Project 2061, federal science agencies, educators and other organizations to identify essential principles and fundamental concepts for Ocean Literacy and related work in other areas of Earth systems science education. References associated with particular key understandings are from AAAS Project 2061 benchmarks and other citations.

What is Climate Literacy?
You are climate literate if you understand the influence of the climate on you and society—and your influence on climate. A climatically literate person:

- understands the essential principles and fundamental concepts (presented in this document) about the functioning of weather and climate and how they relate to variations in the air, water, land, life and human activities in both time and space;

- can communicate about the climate and climate change in a meaningful way; and

- is able to make scientifically informed and responsible decisions regarding the climate.

Climate changes

Throughout Earth's history, climate has changed. Sometimes the change has been slow, over centuries and millennia, influenced by subtle differences in the Earth's orbit or movement of tectonic plates. Sometimes the change is abrupt, when sudden events, such as volcanic eruptions, collisions with meteors or shifts in ocean currents trigger rapid change in the climate. Organisms and ecosystems either adapt to the changes or perish. In human history, climate has influenced civilization in profound ways, playing an integral role in how societies thrive or survive. And in recent years, we have come to learn that human activities such as burning fossil fuels and replacing forests with agriculture are also altering climate. To build sustainable communities and societies that are resilient to natural hazards as well as natural and human-caused climate changes and protect fragile ecosystems, a climate literate citizenry is necessary. This framework for climate literacy seeks to identify and clearly communicate the overarching principles and key concepts that individuals will need in order to make responsible decisions about humans' impact on climate and adaptation to changes in climate for future generations.

As the NCAR Political Scientist Michael Glantz states, the 21st century may become known as the Climate Century, yet the basic dynamics of the atmosphere and climate processes are not easily understood. Many educated adults struggle to understand that Earth's seasonal changes are caused by the tilt of the planet on its axis, or that air has weight, that much of a tree's mass is a function of carbon dioxide in the atmosphere, and trees release invisible, odorless carbon dioxide when burned. Even with recent films, television programs and publications about human impacts on the climate system, there are still many who inaccurately couple the problem of global warming with the hole in the ozone layer.

Climate is an ideal interdisciplinary, integrating theme for education. Beginning with simple concepts and observations of weather and water, and building increasingly complex inquiries and investigation into the physical, chemical, biological, geographical, social, historical and even technological dimensions of climate, students and citizens have the opportunity to better comprehend the interconnectedness of this important topic and make use of this knowledge in their lives and in their communities.

Key definitions:

"Weather" is the state of the atmosphere at a particular place and time and is influenced by climate and many local factors.

"Climate" describes the prevailing or general long-term weather conditions for an area, or for the entire planet.

"Climate System" Earth's water and gasses that flow or change state as a result of the sun's energy

Teaching weather and climate is a substantial yet rewarding challenge that crosses numerous academic disciplines. The Rising Above The Gathering Storm report highlights how the shortage of highly qualified K–12 teachers has forced many of the nation's 15,000 school districts to employ teachers who lack a background in the subject matter that they are asked to teach, and for many years climate has been largely missing from most science curricula. For younger students, the forecasts of melting ice caps and the extinction of species can be emotionally overwhelming, producing "eco-phobia" and a sense of paralysis. Research indicates that some concepts, such as the understanding of how Earth's axial tilt causes the seasons and how longer-term orbital fluctuations affect the distribution of solar energy reaching Earth's surface, require a level of cognitive development inappropriate for younger students. Realizing such limitations, it is nonetheless essential that all citizens and student become climate literate, to the extent they are capable, in order to become aware of the magnitude of the problems and issues, understand the implications of various solutions, and make responsible decisions concerning the climate. We all want to know how to ensure that our future is sustainable.

LIFE & CLIMATE

1. ESSENTIAL PRINCIPLE: Life on Earth has been shaped by, depends on, and affects climate.

FUNDEMENTAL CONCEPTS

a. All organisms are adapted to climatic conditions including temperature, precipitation, seasonal changes, and weather extremes.
b. Changes in these climate conditions can produce very large changes in ecosystems. (Based on AAAS, 5D/H1)
c. Changes in environmental conditions can affect the survival of individual organisms and entire species. (Based on AAAS, 5F/M2b)
d. Human societies have developed food, energy, transportation, and social systems that are dependent on climate and vulnerable to climate changes.
e. These human systems have developed during a relatively stable period in Earth's climate history.
f. Life on Earth, including microbes, plants, animals and human activities, influence climate, sometimes substantially.

Image Source: Randolph Femmer, National Biological Information Infrastructure. Rainforest Vegetation and Waterfall, http://images.nbii.gov/details.php?id=65315&cat=Vines

HOW DO WE KNOW

2. ESSENTIAL PRINCIPLE: We understand the climate system through observation and modeling.

FUNDEMENTAL CONCEPTS

a. Climate science operates under the assumption that Earth's climate system is understandable, and some important aspects are predictable.
b. Data gathered through observations from weather stations, buoys, satellites, ice and ocean sediment cores, tree rings, cave deposits, and other sources provide an understanding of past climates and climate changes.
c. Using observations, logic, and experiments to construct and refine computer models and scientific explanations leads to better understanding of the climate system's behavior and more reliable projections of future climate changes. (Based on AAAS, 1B/H6)
d. Unlike daily weather forecasts, there is limited historical basis of experience on which to judge the accuracy of climate projections. Confidence must be assessed by other methods. These include inferences from prehistoric paleoclimate evidence, and careful process study observations of the causal chain between energy flow changes and climate pattern responses. (**Climate Change:** An Information Statement of the American Meteorological Society, February 2007)
e. Fundamental characteristics of the climate system are understood well enough to support decision-making, even though research continues into many dynamics of climate change. (Based on AAAS, 12A/H3)

Image Source: Forrest M. Mims III, Mauna Loa Observatory at sunset, 2007

SUN DRIVES EARTH SYSTEM

3. ESSENTIAL PRINCIPLE: The Sun is the primary source of Earth's energy

FUNDEMENTAL CONCEPTS

a. Solar energy heats the Earth's surface, which then heats the atmosphere and propels water through the global water cycle.
b. Daily variations in solar energy over the earth caused by Earth's rotation influence many weather processes.
c. The tilt of Earth on its axis causes sunlight to fall more intensely on different parts of Earth during the year, resulting in seasonal changes (Based on AAAS, 4B/H3)
d. Changes in Earth's orbit around the sun over thousands of years alter the spatial distribution and intensity of solar energy received on Earth and impact long-term climate cycles and phenomena such as the Ice Ages.
e. Greenhouse gases in the atmosphere, such as carbon dioxide and water vapor, trap infrared light from the warmed surface of Earth, creating the "Greenhouse Effect" which allows liquid water to exist on much of Earth's surface (Based on AAAS 4B/H4)
f. Sunlight is the ultimate source of most of the energy we use. The energy in fossil fuels such as oil and coal comes from energy that organisms captured through photosynthesis from the sun long ago. (Based on AAAS 8C/H8)

Solar ultraviolet (UV) radiation drives the chemical reactions that produce ozone in both the Earth's upper atmosphere (stratosphere) and its lower atmosphere (troposphere). (Photograph copyright National Center for Atmospheric Research Digital Media Catalog)
http://earthobservatory.nasa.gov/Library/ChemistrySunlight/Images/sunrise.jpg

COMPLEX INTERACTIONS

4. ESSENTIAL PRINCIPLE: Earth's weather and climate system are the result of complex interactions between land, ocean, ice and atmosphere.

FUNDEMENTAL CONCEPTS

a. Energy differences within and between the land, ocean, and atmosphere drive weather and climate variations.
b. Earth's atmosphere and ocean are dynamic systems and impact climate in complex ways
c. Water cycling on Earth is fundamental to weather and climate
d. The water cycle is closely connected to Earth's carbon cycle through biological processes, including photosynthesis and decay, and chemical processes like carbon dioxide dissolving into seawater.
e. Earth's atmosphere is the primary domain of weather and climate factors such as temperature, humidity, air pressure, and wind.
f. Ocean circulation serves as to regulate the temperature of the Earth. Changes in the ocean's circulation have produced large, abrupt changes in climate in the past.
g. Relatively small amounts of greenhouse gases such as carbon dioxide, methane and chemicals such as refrigerants can significantly magnify Earth's Greenhouse Effect.
h. Interactions and feedbacks between components of the Earth's system result in changes to the Earth system and produce (emergent) phenomena unique to the system.
i. Human beings are part of Earth's climate system. Human activities can, deliberately or inadvertently, alter the equilibrium of the climate system. (Based on AAAS, 5D/H3)

At sunset over the Pacific Ocean, anvil tops of thunderclouds cast long shadows. ISS007-E-10807 (July 21, 2003, 35 mm lens). http://eol.jsc.nasa.gov/sseop/images/EO/highres/ISS007/ISS007-E-10807.JPG

NATURAL VARIABILITY & CHANGE

5. ESSENTIAL PRINCIPLE: Earth's weather and climate vary over time and space.

FUNDEMENTAL CONCEPTS

a. "Weather" is the state of the atmosphere at a particular place and time and is influenced by climate and many local factors.
b. "Climate" describes the prevailing or general long-term weather conditions for an area, or for the entire planet.
c. Variations, such as the seasons or weather extremes, can be described by their duration, magnitude or frequency. Different variations range from many years down to a fraction of a second. (Based on AAAS, 11C/M6*)
d. The temperature of a place on Earth's surface tends to rise and fall in a *somewhat predictable* pattern every day and over the course of a year. (AAAS 4B/M12)
e. Differences in the intensity of sunlight warming Earth's surface produce daily, seasonal and very long-term variations in temperature. (Based on AAAS, 4B/H3b)
f. Earth's changing climate states are defined by the average temperature, precipitation, humidity, air pressure, and wind, over long timescales. (Based on AAAS, 4B/H5a)
g. The earth's climates have changed in the past, are currently changing, and are expected to change in the future. (Based on AAAS 4B/H6a)
h. Prediction of atmospheric phenomena requires knowledge/understanding of the components and the interaction of components of the system.
i. Natural processes that drive Earth's long-term climate changes do not explain the rapid changes observed in recent decades or projected for the coming decades.

Image Source: Ryan Vachon CIRES Outreach, Greenland Iceberg

HUMAN ACTIVITIES AND CHANGE

6. ESSENTIAL PRINCIPLE: Recent climate change is primarily caused by human activities.

FUNDEMENTAL CONCEPTS

a. Human beings are a significant part of Earth's climate system.
b. Human activities, such as burning fossil fuels and increasing the amount and variety of chemicals released into the atmosphere, reducing the amount of forest cover, and rapidly expanding farming and industrial growth have changed Earth's land, oceans, and atmosphere and altered Earth's regional and global climate. (Based on AAAS, 4C/M7a)
c. Some changes resulting from human activities have decreased the capacity of the environment to support various species. (Based on AAAS, 4C/M7b)
d. The burning of fossil fuels in the last century has increased the amount of greenhouse gases in the atmosphere, which has contributed to Earth's warming (AAAS, 4B/H6)
e. The observed increase in global average temperatures since the later part of the-20th century is very likely due to the observed increase in human-induced greenhouse gas concentrations, primarily from fossil fuel combustion and deforestation. (Based on IPCC, 2007)

Image Source: US Census, Traffic Jam

MAKING DECISIONS

7. ESSENTIAL PRINCIPLE: Earth's climate system is influenced by human decisions, which are complex and involve economic costs and social values.

FUNDEMENTAL CONCEPTS

a. Decisions about the future involve weighing scientific evidence with uncertainties about future economic growth and energy use, costs and opportunities, moral values, and cultural norms.
b. Informed decision making is more effective when key assumptions and basic facts are clearly identified and understood.
c. Population growth and industrialization increase demands for energy, potentially improving quality of life but also affecting climate worldwide. (Based on AAAS, 7G/M5)
d. The atmosphere is global, and decisions that affect climate (e.g., energy use leading to greenhouse gas release into the atmosphere) made in one region affect people and other species worldwide.
e. The decisions of one generation both provide and limit the range of possibilities open to the next generation. (Based on AAAS, 7C/H3)
f. Decisions about energy use and adapting to climate change are made at all levels, from the individual to the global. (Based on AAAS, 8C/H5)
g. Societal change relative to climate mitigation and adaptation are triggered at the individual and community levels, and by leadership of industry and government. (Based on 7F/H5)
h. Slowing or reversing human's impact on climate change trends can be accomplished by combining short term strategies, such as conservation, efficient use of resources, and the use of renewable resources, with long term investments in technology research and sustainable development strategies.

http://www.nrel.gov/learning/re_solar.html

Further information

For future revisions and changes to this document or to see documentation of the process used to develop this brochure, please visit **http://www.climate.noaa.gov/education/.** In addition, further information relating to climate literacy and climate resources can be found at: earthobservatory.nasa.gov/ www.epa.gov/climatechange/• www.dlese.org/• www.education.noaa.gov

Developing the Guide

This guide is the product of a three day workshop, Climate & Weather Literacy: Using the AAAS Project 2061 Science Literacy Research to Develop Weather and Climate Literacy Framework, in April 2007. An additional workshop, Atmospheric Sciences and Climate Literacy (http://www.eo.ucar.edu/ascl/), workshop in November 2007 along with extensive follow-up communications among some 100 members of the climate sciences and education communities. The National Oceanic and Atmospheric Administration (NOAA) sponsored the first workshops along with the American Association for the Advancement of Science (AAAS), organizers included, NOAA, NASA Goddard Space Flight Center, and the US Climate Change Science Program's Communications Interagency Working Group and it was hosted by the Department of Commerce and the NOAA Office of Education. The event was planned and coordinated by Ted Willard, AAAS Project 2061; Frank Niepold, NOAA Climate Program Office; Christos Michalopoulos, NOAA Office of Education; and Jon Lilley, NOAA Office of Education. Principle authors of the guide were Frank Niepold, NOAA Climate Program Office and Mark S. McCaffrey, Cooperative Institute for Research in Environmental Sciences (CIRES)/University of Colorado- Boulder

NOAA, AAAS Project 2061, NASA, CIRES, American Meteorological Society, and various members from both the science and education community worked to define climate literacy in the United States. Supported through a NOAA Education Grant, the workshop brought together over twenty individuals representing various numerous NOAA line offices, other federal science agencies, formal and informal educators, non-governmental organizations, and other vested institutions involved with climate research, education and outreach to work together towards the goal of building of a framework for climate and weather literacy, building on the research and science and technology education benchmarks developed by the American Association for the Advancement of Science (AAAS) Project 2061.

The workshop developed the initial framework through an iterative process rooted in scientific research, including education and social research, on weather and climate related topics. Conducted as an initial step with broad community involvement toward the development of a robust conceptual framework that will help address misconceptions about weather processes, the workshop focused on natural as well as human-induced climate processes, the workshop sought to identify the key and essential concepts that a climate literate citizen or student should know. A core group continues to pursue developing the envisioned climate literacy product after the end of the workshop. Broader participation by other agencies, non-governmental organizations, and individuals was sought through extensive review comment periods. A NSF/NOAA funded follow-up workshop in November 2007 in Boulder Colorado contributed substantially to the refinement of the current framework.

All draft and final reports will be posted at NOAA's Climate Program Office's Education site, http://www.climate.noaa.gov/education/.

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